- SCHEDULING STANDARDS

PILOT PROJECT -

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S U M M A R Y

This pilot project has investigated the use of engineered labor standards, specifically the MOST system, to establish standards useful for shop loading and scheduling. The key element in the investigation is the development of the nonprocess factors. The present report describes the data, procedures, and results for this development.

Development of the nonprocess factors followed two parallel tracks. In the first, samples of work orders were closely monitored in the fabrication shop, and the actual production times were compared to MOST level times. Statistical and other analyses were used to develop explanations for the differences between the level times and the actual times.

The second line of investigation examined the content of the existing labor standards, the actual work performed in the shop, and observations of the total fraction of time applied to production. This investigation also considered worker pace as an important variable in setting scheduling standards.

It would be fair to say that the first track was a “did cost” analysis of shop performance, while the second track was a “should cost” analysis of shop performance. Not surprisingly, the did cost results are consistently higher than the should cost estimates, as discussed below. Several factors are identified later as evident or potential contributors to the difference.

One of the primary conclusions of the pilot study is that the actual production times are highly correlated with the level times as well as the attributes of the pipe details themselves. Thus, the level times do provide one good basis for predicting the actual time required for a task.

Another primary conclusion is that, with certain limitations, even a very simple method for converting the level times into scheduling standards can give good results. More. complicated methods for obtaining scheduling standards from the level times give more accurate results, but the improvements are decreasing as. the effort increases.

1. DATA COLLECTION

The basic data required in the pilot study includes both the MOST level time and the actual production time for individual pipe details. The MOST level times for the first trial were obtained from the "detailed" MOST data base, i.e., by examining each pipe detail, and determining a time for each operation for the detail based on material and pipe diameter. This time consuming process was replaced by "classification" MOST for the second and subsequent trials. Classification MOST requires only counting the operations (number of pieces, number of bends, number of joints, etc.) and the use of simple charts to determine the level times. Samples of the work sheets and charts are included in the appendix.

The actual production time for each pipe detail *was* obtained from a time sheet maintained by the individual mechanics i-n the shop . The time sheet consisted of 15 minute intervals, and the mechanic was asked to record the detail and type of work performed during each interval. A sample of the time sheet is included in the appendix. The time sheets were collected on a daily basis, verified as to work order and pipe details, and any problems (such as detail reported which is not in work order) were resolved during the following work day. During the second and subsequent trials, the mechanics were instructed to identify any work that was not specific to a particular pipe detail, e.g., clean up work station, order material, etc.

In addition to the data on pipe details, during each trial a work sampling was conducted. A sample af the daily log for the work sampling appears in the appendix. Front the work sampling, the average fraction of time can be computed for *several* categories, especially for process time.

Information regarding normal work practice, paperwork flow and so forth *was* obtained by interviewing shop personnel.

Table l.l, summarizes information about the details from the first two trials that were included in the statistical analyses. It should be noted that several work orders. from the first trial were excluded from the statistical analysis because the reported times contained details which were not in the sample work orders. These and other discrepancies were excluded for the purpose of estimating parameters”

From Table 1.1., it appears that the Cu details were roughly comparab in the first two trials, although the details in the first trial required slightly more bending on the average and had slightly fewer joints. The CuNi details, however, were substantially more diifficult first tr For example, they had more than twice as many bends on the average, almost fifty percent more joints, and slightly larger diameters. .

Table 1.1 also demonstrates the differences between material groups with regard to the complexity of the details. The Cu details tend to have the most bends and joints, and are almost exclusively smaller than three inches in diameter. The steel and stainless steel details tend to have larger diameters with almost fifty the details being over three inches. Almost all the stainless steel details require no more than two joints, while over fifty percent of the copper details require more than two joints.

TABLE 1.1

MATERIAL	NUMBER OF DETAILS	% OF TOTAL	AVER TIME	MAX TIME	AVE NUM BENDS	% WITH NO BENDS	AVE DIA	% WITH DIA LE 3"	AVE NUM JOINTS	% WITH LE 2 JOINTS
FIRST TRIAL										
CU	22	21	1.43	3.30	0.77	32	2.10	100	4.41	-
CUNI	83	79	1.09	4.10	0.70	57	2.86	72	3.02	-
SECOND TRIAL										
STL	18	14	0.87	1.60	0.28	89	3.11	50	2.33	83
CRES	32	24	0.68	1.65	0.34	88	4.13	53	1.38	97
CU	43	33	1.36	3.40	0.60	63	1.77	91	4.86	42
CUNI	39	30	0.79	2.00	0.26	87	2.69	85	2.26	72

2. DID COST ANALYSIS

The did cost analysis was based on *a* direct comparison of level time and actual time, by detail. The actual times for each detail were totaled from the mechanics' time sheets and presented in a summary form. A sample of this form is given in the appendix. Note that a particular detail might be worked on by a mechanic on several different days, and also might be worked on by several different mechanics. The summary sheet also includes the level times for fabrication and for bending (only the bending not done on a SIS).

The summary sheet along with the level time work sheet gives all of the relevent information about each pipe detail. Information about the make-up of the detail (material, size, complexity) was used at certain points in the analysis to try to explain differences between the level time and the actual time.

2.1 Relating Actual Time to Level Time

The pilot project is foued on the assumption that actual production time is related to level time in such a way that level times can be used develop accurate estimates of the actual time. One problem, then, is to discover the form of that relationship, if it does exist. Tare areseveral possibilities to examine.

Ratio Relation. thesimplest relationship between actualtime and level time would be for actual time to be proportional to level time. thatis:

$$AT = (DCF)(LT) \tag{2-1}$$

where AT is the actual time for a detail

LT is the level time for a detail

DCF is the "did cost factor" *or* constant of proportionality

This relationship is appealing because of its simplicity. It also seems reasonable that, if the level times underestimate actual times (because of shop delays and other nonprocess factors) that the degree of underestimation should be proportional to the amount of work in the detail.

Linear Relationship. An alternative model is for actual time to be linearly related to level time:

$$AT = b_0 + b_1 \times LT \tag{2-2}$$

where b_0 is the intercept of the line

b_1 is the slope of the line

Essentially, this model is based on the assumption that in addition to a proportional relationship between actual time and level time, there is some "shop constant" or delay that occurs for each detail.

Other Relationships. Other forms for estimating actual production time can be considered. In particular, it seems likely that the actual time will depend not only on the level time, but also on the characteristic of the detail. Some types of operations, e.g., bending, may always involve greater delays than others. Or larger diameters of pipe may involve greater delays than smaller diameters for similar details. One model that was examined briefly was:

$$AT = b_0 + b_1 \times LT + b_2 \times DIA + b_3 \times PCS + b_4 \times JNT + b_5 \times BND \tag{2-3}$$

where DIA is the pipe diameter

PCS is the number of pipe pieces in the detail

JNT is the number of made up joints in the detail

BND is the number of bends required

2.2 Estimating Parameters

Inevaluating possible relationships between level time and actual time, two questions *are* important:

(1) Given a sample of details, does the relationship explain the observed data?

(2) Given parameter values based on previousexperience, does the relationship do a good job of predicting?

To answer either question, the parameters in the relationship, or model, must be estimated. The technique used for parameter estimation was least squares regression analysis. This technique uses sample data and determines parameter values that minimize the sum of the squared differences.between observed times and estimated times. Because squared differences are used, larger deviations are considered more important.

The computer package used for the regression analysis made it convenient to group the details in various *ways.* By looking anvarious groups of de-tials and comparing the parameter estimates, .it is easy to isolate **the** important factors in determining actual production **time.**

Ratio Relationship. Table 2.1 summarizes the results of estimating the parameter, DCF, for data from the **first two** trials. Note first that the estimates for the Cu and CuNi material groups *are* almost identical for both trials, despite the..fact that the CuNi details inthe second trial tended to be much simpler (i.e., fewer bends, smallerdiameter, and fewer joints). Also, the parameter values for each material group seem to be stable across the different detail groups, For example, the DCF values for Cu details is 1.53 over all Cu details, 1.41 for details smaller than three inches in diameter, 2.32 for details with two pieces or fever, and 1.26 for details with no bending. Only the value for the subgroup “two pieces

TABLE 2.1

SUBGROUP		STEEL	CRES	CU	CUNI
All Details- first trial	R^2			.87	.82
	SEOE			.94	1.50
	RMS			.88	2.24
	DCF			1.47	2.22
				(1.55)*	(2.26)
All Details- second trial	R^2	.81	.80	.83	.80
	SEOE	1.18	.46	1.13	1.05
	RMS	1.40	.21	1.28	1.11
	DCF	2.54	1.16	1.53	2.26
		(2.43)	(1.36)	(1.66)	(2.69)
Diameter $\leq$ 3"- first trial	R^2			.87	.75
	SEOE			.94	1.01
	RMS			.88	1.02
	DCF			1.47	1.71
Diameter $\leq$ 3"- second trial	R^2	.82	.81	.85	.85
	SEOE	1.39	.40	.96	.89
	RMS	1.93	.16	.92	.79
	DCF	2.74	1.48	1.41	2.13
No Bending- first trial	R^2			.65	.77
	SEOE			1.32	1.53
	RMS			1.73	2.34
	DCF			1.26	2.11
No Bending- second trial	R^2	.85	.79	.84	.80
	SEOE	.86	.44	.92	1.10
	RMS	.75	.20	.85	1.20
	DCF	2.21	1.14	1.26	2.26
Two Pieces or Fewer- second trial	R^2	.81	.80	.83	.82
	SEOE	1.21	.46	.65	.91
	RMS	1.46	.21	.43	.82
	DCF	2.73	1.39	2.32	3.02

R^2 : the multiple R^2 coefficient
SEOE : standard error of the estimate
RMS : residual mean square
DCF : did cost factor

* values in parentheses are the total actual time for the subgroup divided by the total level time for the subgroup

or fewer'"is significantly different from ***the othevalues*** Likewise, only the "two pieces or fewer" subgroup is out of line for CuNi details, and only

ending" -subgroup is *out* of line for the steel details. This indicates that the relationship is relatively stable over the range of details included in the sample. It does not, however, permit any conclusion about details that might fall outside the range represented in the two sample'.

Obviously, there are significant differences across the material groups. The DCF values are 2.54, 1.16, 1.53, and 2.26, with the largest being over twice the ***smallest.*** At this point, it is ***not*** possible **to say why this** range of values is observe It is important **to** note, as emphasized earlier, - that the values are stable within-materialgroups, so that the differences across material groups are not due to just random factors

The **values** of R^2, SEOEnd RMS are indicators of how well or poorly the model with the estimated parameter values explains the variations in the sample. It might appear that the ratio relationship is a pretty good model, based on the values ofR^2, SEO^E and RMS. There is, unfortunately, a real but not obvious problem with this model. In technical terms, the residuals are highly correlated with the independent variable, LT. What this means in practice is **that** if this model is used for prediction, the results will tend to be too small for a11 values of LT, and too large for **large** values of LT. Thus, good prediction results can only occur if the details being estimated have level times which are near the average level time for the sample used to estimate the parameter, DCF.

In conclusion, the ratio relationship is not a good model ***to*** use for prediction. It does, however, give stable parameter estimates across samples and across subgroups within samples. Thisindicates that the actual times are correlated withlevel times and that other relationships might also give stable parameter estimates and be useful-for prediction as well.

For information purposes, Table 2.1 also showsthe values for the did cost factor thatwould be obtained by simply taking the ratio of average actual time to average level time (or total actual time to total level time). Note that these values seldom agree exactly with the values from the regre-ssion analysis, and in some cases the difference is substantial, e.g., for the CuNi details in the second trial. The reason for this difference is that simply taking the ratio of the total times assumes that all differences between predicted values and observed values are equally important. For example, one difference of +.50 is no more important than two differences of -.25. The regression analysis would consider the single large difference to be more important.

Linear Relationship. Table 2.2 summarizes the results of the various regression analyses for the linear model (2-2). Comparingthe results for the first trial *to* those for **the** second trial reveals thatthe parameters for Cu details are virtually the same, while those for the CuNi details are dramatically different. Recalling that the CuNi details in the second trial were quite different from those in the first-trial, it seems reasonable to conclude that actual time is predictable.

The parsmetervalues differ significantly across the four material groups, as they did for the ratio relationship. Again, this indicates that materialtype is **a** significant factor in determining performance against the level times. Also, looking at the parameter values for a given material Acrossthe several subgroups, it is clear that the detailattributes are alsoimportant factors. For example, the parameters for the Cu details are ‘elatively stable across subgroups, except for the “no bending” subgroup. imilarly,the CuNi parameters are stable except for the “two pieces or

TABLE 2.2

SUBGROUP		STEEL	CRES	CU	CUNI
All Details- first trial	R^2			.51	.63
	SEOE			.93	1.51
	RMS			.87	2.27
	b_0			.48	.11
	b_1			1.21	2.16
All Details- second trial	R^2	.51	.17	.51	.32
	SEOE	1.19	.35	1.09	.84
	RMS	1.42	.12	1.19	.70
	b_0	- .60	.64	.60	1.23
	b_1	3.13	.42	1.22	1.14
Diameter $\leq$ 3"- first trial	R^2			.51	.40
	SEOE			.93	.96
	RMS			.87	.92
	b_0			.48	.55
	b_1			1.21	1.27
Diameter $\leq$ 3"- second trial	R^2	.71	.16	.56	.46
	SEOE	1.20	.33	.90	.66
	RMS	1.44	.11	.82	.44
	b_0	-2.32	.55	.62	1.11
	b_1	4.88	.58	1.09	1.15
No Bending- first trial	R^2			.00	.56
	SEOE			1.27	1.55
	RMS			1.62	2.39
	b_0			1.67	.02
	b_1			.07	2.10
No Bending- second trial	R^2	.37	.14	.54	.33
	SEOE	.89	.34	.79	.87
	RMS	.79	.11	.63	.75
	b_0	.29	.62	.81	1.26
	b_1	1.91	.39	.86	1.15
Two Pieces or Fewer- second trial	R^2	.56	.19	.15	.30
	SEOE	1.21	.35	.63	.81
	RMS	1.46	.12	.40	.65
	b_0	- .74	.63	.68	.92
	b_1	3.50	.45	1.26	1.73

R^2 : the multiple R^2 coefficient
SEOE : standard error of the estimate
RMS : residual mean square
b_0 : intercept parameter for linear model
b_1 : slope parameter for linear model

fewer" subgroup. Results for the steel **details** are different in each subgroup.

Technically, the linear relationship provides a better model than the ratio relationship. In general, the residual mean squares are smaller, the residuals are not correlated, and tend to have a **smaller** spread. Thus. the linear relationshipwould be expected to perform better in predicting the actual time based on level time.

Detailed examination of the residual plots revealed the presence of "outliers" in each material group. These are details for which the difference between the observed actual time and the time predicted by the model are much greater than for the rest of the details. If some assignable cause for the excessive difference canbe determined (e.g., mischarging ofhours, then it is **legitimate** *to* exclude that point from the sample for the purpose of parameter estimation. Assuming that someassignable cause could be found, the regression analysis was repeated,without the outlier details. Table 2.3 summarizes the results of that analysis. There is only a slight improvement in the R^2 values, but a substantial reduction in RMS. Note that the resulting parameter values are virtually unchanged except for the steel details.

Other Relationships. Several other regression models **were** tested, but none of them was dramatically better than the simple linear relationship (2-2). ITis of **interest to** note, however, that very good results were obtained using **a** linear relationship between actualtime and the detail attributes diameter, number of pieces, number of joints, number of bends, diameter times number *of* joints, and diameter times number of pieces. The results for this modelare summarized in Table 2.4, and indicate that this model is superior to the simple linear relationship between level time and

TABLE 2.3

SUBGROUP		STEEL	CRES	CU	CUNI
All Details-second trial	R^2	.51	.17	.51	.32
	SEOE	1.19	.35	1.09	.84
	RMS	1.42	.12	1.19	.70
	b_0	- .60	.64	.60	1.23
	b_1	3.13	.42	1.22	1.14
Outliers removed-second trial	R^2	.44	.22	.72	.50
	SEOE	.70	.29	.66	.58
	RMS	.49	.09	.43	.33
	b_0	.26	.61	.62	1.17
	b_1	1.71	.41	1.13	1.10

R^2 : The multiple R^2 coefficient
SEOE : standard error of the estimate
RMS : residual mean square
b_0 : intercept parameter for linear model
b_1 : slope parameter for linear model

actual time.

It should be emphasized that the model reported in Table 2.4 is not necessarily the best model for predicting the actual detail fabrication times. In each material group, some of the independent variables are strongly correlated, leading to negative regression coefficients. The proper conclusion is that it is possible to construct a regression model that will give good estimates of the actual time, although considerable additional data gathering and analysis migh be required.

TABLE 2.4

	STEEL	CRES	CU	CUNI
R^2	.74	.45	.69	.45
SEOE	1.06	.31	.33	.81
RMS	1.12	.10	.87	.65
b_0	.04	.33	-1.36	1.01
b_1 (DIA)	.11	.10	1.34	.16
b_2 (PCS)	-3.00	.45	.25	-1.10
b_3 (JNT)	2.81	- .38	.18	.97
b_4 (BND)	.36	.26	.62	.08
b_5 (DXJ)	- .66	.08	.10	- .27
b_6 (DXP)	.93	- .08	- .27	.44

2.3 Prediction Capability

A very preliminary test of the prediction capability of the regression models can be performed by using the parameters estimated from the first trial to predict the actual times for the second trial. The relevant data from the second trial are:

material	num. det.	lev. time	act. time
Cu	43	58.56	93.50
CuNi	39	31.00	83.25

The predictions using both models and the parameters from the first trial are:

for Cu details

$$AT = (1.47) \times (58.56)$$
$$= 86.08$$
$$AT = (43) \times (.48) + (1.21) \times (58.56)$$
$$= 90.18$$

for CuNi details

$$AT = (2.22) \times (31.00)$$
$$= 68.82$$
$$AT = (39) \times (.11) + (2.16) \times (31.00)$$
$$= 71.25$$

In both cases, the linear relationship gives a more accurate prediction than the ratio relationship. Note that the larger percentage error for CuNi details is due to the difference in difficulty of the details in the two samples.

A more complete test of the prediction capability would be to take the parameters for the best regression models determined for the second trial and use them to predict actual times for a third trial.

2.4 Other Analyses

Not all work in the shop has an engineered labor standard. In the second trial, the mechanics were instructedto record any such work separately from the detail fabrication times. For the seventeen work orders in the sample, 52.50 hours, or 14%,were so recorded. Although there is not enough data to warrant regression analysis, itappearsthatthe nonstandard hours are correlated somewhat with the total hours in the work order It is very likely that additional nonstandard workwasincluded in the detail fabrication times.

A questionofme concern in the pilot has been whether or not there are substantial differences in the mechanics' proficiencies. The following analysis may shed. some light on the subject. Generally, a work order is given to one mechanic, although some work may be done by other mechanics on that workorder. For each mechanic in the shop, the set of work orders assigned to **him** in the second trial was identified. Table 2.5 presents an analysis by these groups of work orders. In the table, the values for "Allowed Timearedetermined using the ratio relationships, by material type, with the parameters estimated from the <u>second</u> trial. The **values** for "Efficiency" are determined by dividing the alloved times by the actual times. Note that the actual work order times include some nonstan*rd hours so that efficiency for the shop is about 85%.

AStheable illustrates, there are substantial differences between the mechanics. It should be emphasized that this is only a crude comparison, because somemechanics work on almost all the work orders. However, if this doesn't distort the results excessively, then the conclusion stands.

TABLE 2.5

	MATERIAL	ACTUAL TIME	LEVEL TIME	ALLOWED TIME	EFFICIENCY	
Group 1	STEEL	2.75	1.14	2.90	1.05	
	CRES	12.50	5.84	6.77	.54	
	CU	2.50	4.02	6.15	2.46	
	CU	6.00	3.88	5.94	.99	ave = .92
Group 2	CUNI	3.75	2.92	6.60	1.76	
	CUNI	29.75	12.51	28.28	.95	
	CU	45.25	23.38	35.77	.79	
	STEEL	9.25	3.66	9.30	1.01	ave = .91
Group 3	CUNI	13.50	3.34	7.55	.56	
	CU	17.75	7.36	11.26	.63	
	CRES	30.50	15.60	18.10	.59	ave = .60
Group 4	CU	52.50	26.38	40.36	.77	
	CUNI	20.75	6.80	15.37	.74	
	CUNI	39.50	12.75	28.82	.73	
	STEEL	39.25	9.12	23.16	.59	ave = .71

2.5 Conclusions from Did Cost Analysis

The primary conclusion from the **did cost analysis** *is* that the actual time to fabricate a pipe detail is highly correlated with the level times and detail attributes, andtherefore Predicta Statistical analyses of limited amounts of data produced regression models of the actual fabrication times that were satisfactoryforprediction.

Thestatisticalanalyses have revealed a number of important factors in determining actual times, such as material type and detail attributes. However, the statistical analyses c-not reveal whyfactors are impo tant. That requires a more in-depth examination of the standards and the production process.

3. SHOULD COST ANALYSIS

The should cost analysis was based on considerationof four factors: level times, process time, nonstandard work, and worker pace. Level tines are the MOST engineered labor standards. The process time estimates come from the work sampling conducted during each trial. The nonstandard work was estimated from the did cost analysis results. Pace was neither observed nor estimated, but simply recognized as- an important factor.

3.1 Level Time

The level timegive for a particular pipe detail includes all material handling and set up time necessary for that detail. A 100% pace is assumed in developing the level times. The leveklytimesshcedule 15% allowance for PF&D (personal time, fatigue, and delay).

3.2 Actual Time

The actual time recorded by the mechanics includes any delay time or personal time other than breaks. It also reflects the mechanic.'s actual pace, although there is no way to measure pace directly from the actual times. The actual *timesrep* for detail fabrication may also include some nonstandard time, even though the mechanics were instructed to record this separately.

Actual time is obviously affected by process time (average amount of time each day spent in fabrication) and by pace. Both these, in turn, are . directly affected by "shop load," or the amount of work available in the shop. If there is no backlog of work orders, then the pace (intensity with which work is done) and the process fraction will decline. As a resuit, the actual time to fabricate a particular detail vill tend *to* be greater when the shop is underloaded than when it is full loaded.

3 Should Cost Factor

A should cost factor, or SCF, was developed to correct the level times r the actual PF&D and to account for the nonstandard work. The correction oceeds in the. follwing steps:

(1) remove the 15% PF&D allowance from-the level times;

divide by 1:15;

(2) **add allowance for the observed PF&D;**

divide by PF, where PF is the process fraction;

(3) adjust for the nonstandard work content:

multiply by l/SWF, where SWF is the fraction of total time corresponding to work for which there are standards.

lring the second trial, the obsened value for PF was 0.58. From the did >st analysis, SWF vas estimated as 0.86. Using these values gives

$$SCf = 1 / (1.15 \times 0.58 \times 0.86)$$

$$= 1.74$$

a other words, the actual time reported should be 174% of the level time or the work orders assigned to be fabricated during the trial.

For the seventeen work orders in the third trial, the ratio of reported ime to level time was 2.35. Clearly the did cost figure was substantially rester than the should cost figure. One possible source of the difference s shop load and pace. Suppose this is the only explanation for the dif-erence. Then it may be inferred that the average pace during the second .rial was 1.74 / 2.35 = .74, or 74% instead of the assumed 100%. Of course, here could be other explanations, such as equipment breakdown, power out-lge, material delays, etc.

344 Comments

In developing the should cost factor, there was an implicit assumption that the level times were internally consistent, that is, that they would be equally effective in predicting actual times-across materials and pipe detail attribute. From the did cost analysis, it appears that this assumption *is* incorrect and that for some reason, the level times do not appear to be consistent. This introduces some severe problems into the development of a should cost factor based on level times. Foremost among these problems is how to differentiate the should cost factor across material groups and detail attributes. thisapparentinconsistencymioghtasily explained by methods variances between that which is specified in the standard and that which is actually followed on the shop floor. .Other possible explanations could be offered, but without retruingtoa large scale monitoring function to search for causes, the data alone cannot tell one the cause.

The should cost factor as developed inhis section incorporates the level time assumption of 100% pace. It therefore provides away to set achievement goals for production, since the only way to improve on the should cost time *is to* work at greater than 100% pace or *to* reduce the amount of nonstandard vork. The did cost factor developed from the statistical analysis provides a wayto monitor achievement, ‘since it represents a level that has been demonstrated in the past..

4. NONPROCS FACTORS

It is reasonable to expect that actualroduction time will differ from " level times for completely natural and-acceptable reasons. For example, there may be congestion in the shop that cannot be accurately reflected in the individual pipe detail level times. However, there may also be specific factors contributing to the difference between level times and actual times. The identification and quantificationof these factors is important; since it is the first step to eliminating them.

4.1 Delays

One of the first sources considered for specific nonprocess factors was that of delays occuring at special equipment. Two types of-equipment were analyzed. Apparently, the Marvelaw is used for about 95%of the pipe cutting in the shop. There is a "fast cutoff saw, but it is rarely used. Given the amount of pipe cutting in the shop, *it seems* reasonable that there might be some delays at the saw. Also , despite the fact that there are three Greenlee benders in the shop, normal work practice is to have a single individual perform all bending. Therefore, we might also expect some delays in bending.

Sawing. During the second trial, there were six mechanics working on the work orders being followed in the shop. For the fabrication work orders, there were morethan 330 pipe pieces. Since standard work practice is to provide pipe with extra stock,. this generates at least 330 saw cuts. In addition, there were 91 saw cuts from bending work orders on the Conrac bender. On the average, about 5 saw cutswererequiredevery hour. The MOSTlevel time for sawing is never less than 0.05 hours or 20 cuts per hour. **Assuming** that the need to cut pipe occurs randomly (that the needs don't bunch up early in the "day or late in the day) this situation can be evaluated using standard queueing analysis. One result of such analysis is that the average waiting time at the saw is 9.3 minutes per saw cut. Over the two week trial, this would amount to 65 hoursofdelay time.

It is quite likely that 65 hours is an overestimate. A mechanic may be ready to go to the saw, lookup and see that *the saw* isbeingused, and spend the waiting time setting up for his next operation. However, it is quite unlikely that **all** of the waiting time is used productively.

Bendins. Also during the second trial> there were five mechanics working on fabrication work orders. In those work orders, there were a total of 52 bends, or 0.65 bends per hour. The average *time* per bend is not less than 0.15 hours, or 6.6T bends per hour. Again, assuming that the needs for bending occur at random, standard queueing analysis gives an average waiting time of 5.25 minutes. per bend, or 4.5 hours over the two week trial period. It seems unlikely that delays az the bending operation are a significant s contributor to nonprocess factors.

4.2 Shop Loading '. - . · I

Another factor that may affect nonprocess factors is the shop load itself. If the shop is significantly under loaded, it is only natural *that* the hours charged to the available work orders will grow to cover *the man-*hours in the shop. Shis may manifest itself in a reduction in pace, or in the inclusion of more nonstandard work, sach as housekeeping, maintenance, and so forth.

4.3 Foreign Jobs

A third element in the nonprocess factors is work that is brought into the shop for special treatment. Examples *are* large diameter bending jobs. Quite often, such jobs cannot legitimately be charged to work orders in the shop, and so the hours are simply added to some other legitimate work order.

5.0 OTHBR **OBSERVATIONS"**

During the course of the pilot, several factors outside the jurisdiction of the pilot project were observed to impact the effectiveness of pipe fabrication.

5.1 Shop Layout

The layout of the pipe fabrication shop appeus to cause unnecessary material handling congestion and delay. This is particularly **true** with regard to the location of the material saw. This saw is apparently usedby all mechanics for mostof the pipe cutting> but is not centrally located and not easily accessible.-

The analysis in section 4.also indicates the possibility that a second saw is needed If this is the **case**, then the location of the second saw should be chosencareful,andselocation of the existing saw should be considered.

5.2 Short Intervalschedulin

Fabrication work orders are developed within the System Work Breakdown Structure. The content of a fabrication work order is based on a planned installation sequence by'zone. thisiworkswellas long as the actual installation sequence is the same as the planned sequence. When these two sequences are differenthoweverthere are problems .caused by the installation of some, but not **all,** details on a work order.. When this occurs, the level of work in process, and the problems associated with material handling, storage and control all increase.

The problem seems to be one of not being able to identify particular details needed **over a** short period of time so that they can be fabricated, without regard. to their original SWBS work order. A similar problem existed in loading work on the Conrac bender. That problem was solved by creating the bending work orders, which are outside of SWBS. The bending work order may include pipe details from several SWBS work ordezs. This allows similar sizes and materials to be grouped to maximize the efficiency of the automatic bending operation.

The problem with releasing work to the fabrication shop is similar, but not identical. For the automatic bending operation, the grouping needed was based on similarity of size and material. For the fabrication operation, the grouping needed is based on similarity of installation time. Note that it is diffcult, if not impossible, to determine installation time (within, say, 5 days)ofa pipe detail at the point in time when the SWBS work orders are typically defined.

The fundamental difficulty is that the definition-of the work orders is fixed longin advance of the actual fabrication and installation, and it is not possible to make changes to large numbers of work orders over the short period oftime in which the actual installation sequence becomes known. The ideal solution would be to release work orders to a “ready pool” from which production could select individual pipe details for fabrication as needed. This wouldresult in a steady flow of fabricated pipe details from the fabrication shop to the waterfront, with storage used only to balance the work between the two. Presently, intermediate storage of details is thele rather than the exception.

Another cause of methods changes is the aftermath of process changes. Changes in equipment and tooling, e.g. moving from manual bending to nearly automatic pipe bending, or merely tackw CRES joints rather than complete welding, as an example of a process change, will likely resultinmethodschange with Signigicantly different work content. Process changes are usually instigated by conscious manag-nt action and thereforethese should automatically "tri gger' methods engineering for at 1 east the specific tasks affected by the process.

Design engineering changes can also t ead to methods changes. Material and tolerance changes are prime examples where significant methods changes may result. As with process changes, the design engineering changes can be monitored to see if such a change should trigger a methods audit.

Layout changes, distinct from process changes, may also 1 ead to methods alterations. The reduction of walking distances, as one example, may significantly change the total work content of a task Oy group of tasks. Manylayout alterations are subtle,perhaps being accomplished withinonly the oversight of first level supervision, and so these may bedifflcult for higher management to monitor. ,Other layout changes, such. as the introduction of an additional saw or pipe bender, are not subtle and the effects of the layout change or work method on non-oricesscanbe assessed

WHEN considering the non-process factors and the 1eveltimes developed in conjunction with this project, it. is also c1ear that

a. Periodic methods audits

b. Process change trigger

c. Layout change triggers

d. Design engineering change triggers

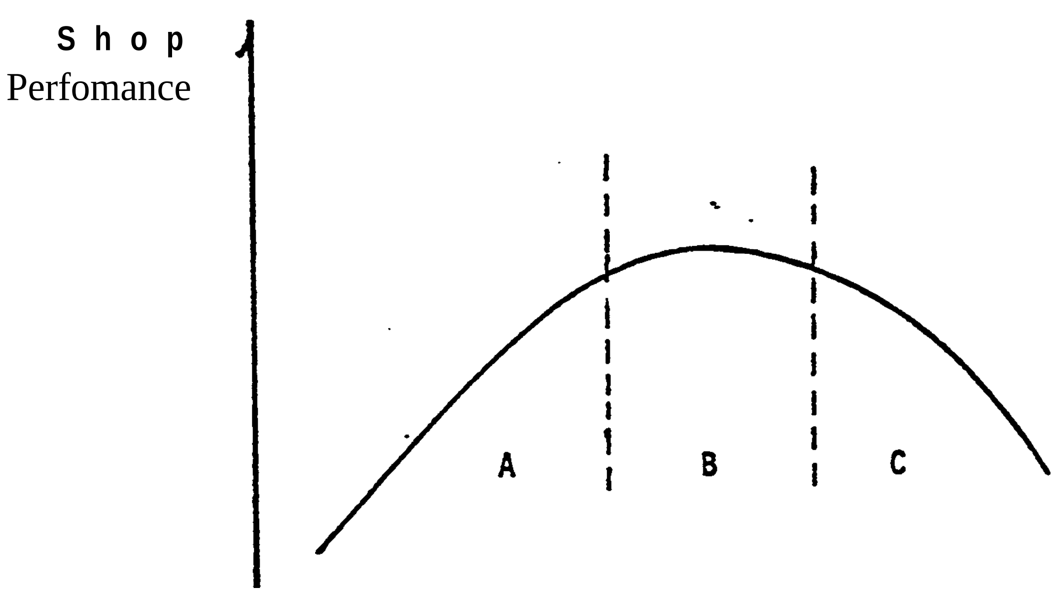
e. Monitoring shop performancegainst assigned load

5.4 Measuring Shop Capacity

The dynamic nature of the shop capacity when considering the machine capacity and laborcapacity simultaneously'makes this problemof capacity "measurement particularly difficult. The introduction of new **shop** loading standards which recognize delays resulting fromcapacitaed centers in the shop my serve as. a useful tool by which to examine working **ShOp** capacity. .

Suppose it is the case that shop performance against measured work was only 74% in the second trial rather than 'de assumed 100%. It is conjectured that one cause for this lower pefiormance was an underloaded shop where the short-term excess labor capacity was readily adjusted through a decrease in worker pace. Under such conditions, the level times and the non-process times,which bot assume 100% pace, would both be"affected. Another cause for lower performance might be excessiveshop loading where congestion and delays result from the lack of capacity. When this condition exists, . it is likelythattheactual non-process times **will** exceed the non-process times incorporated in the loading

This can be graphically portrayed as fotows:



APPENDIX

ESTIMATING STANDARDS

BENDING ONLY. INCLUDES SET UP

COPPER - COPPER NICKEL

No. of Bends	1"	2"	3"	4"	5" •	6" •	No. of Bends
1	.18	.18	.18	.18	.32	.32	1
2	.32	.32	.32	.32	.50	.50	2
3	.32	.32	.32	.32	.50	.72	3
4	.50	.50	.50	.50	.72	.72	4
5	.50	.50	.72	.72	.98	.98	5
6	.72	.72	.72	.72	.98	1.3	6
7	.72	.72	.72	.98	1.3	1.3	7
8	.72	.98	.98	.98	1.3	1.6	8
9	.98	.98	.98	.98	1.6	1.6	9
10	.98	.98	1.3	1.3	1.6	2.0	10

CRES, BLACK STEEL, & GALVANIZED

No. of Bends	1"	2"	3"	4"	5" •	6" •	No. of Bends
1	.18	.18	.18	.18	.32	.32	1
2	.32	.32	.32	.32	.50	.50	2
3	.50	.32	.32	.32	.72	.72	3
4	.50	.50	.50	.50	.98	.98	4
5	.72	.72	.72	.72	.98	.98	5
6	.72	.72	.72	.98	1.3	1.3	6
7	.72	.98	.98	.98	1.6	1.6	7
8	.98	.98	.98	1.3	1.6	1.6	8
9	.98	.98	1.3	1.3	2.0	2.0	9
10	1.3	1.3	1.3	1.3	2.0	2.0	10

• ADD FOR ROSIN FILL: 4.0 HOURS EACH 20 FT. LENGTH.

GREENLEE

VSIS FORM 1038A
1/80

70 OBS

	6:45-7:45	7:45-8:45	8:45-9:45	9:45-10:45	10:45-11:45	12:15-1:15	1:15-2:15	2:15-3:15			TOTAL OBS	% OBS	TOTAL TO DATE	% OF TOTAL	
ROCESS TIME:											49	70%	49	70%	
AWING	1	1 CN	1 CN			1 CN	1 CN				5				
ND PREP		1 CN									1				
ENDING		1 CN	1 CN	1 CN	1 CN	1 CN	11 CN	11 CN			9				
IT & TACK	1 CS	1 CS									2				
ELD															
AYOUT & MEASURE	1										1				
RAZING		11 CN		11 CN		1 CN					5				
NSPECTION															
AREHOUSING ([illegible])	1		1 CN								2				
LEANING PIPE															
[illegible] Benchwork	11	11 CN	111 CN	111 CN	111 CN	1111 CN	1 CS	111 CN			23				
[illegible]						1					1				
NAVOIDABLE DELAY:											13	18.6	13	18.6%	
ECEIVING INSTRUCTION	1		1				1	1			4				
INSTRUCTING					1		1				2				
READING LIGHT Print	1		11 CN	1 CN	11						6				
CLEAN-UP				1 [illegible]							1				
NON-PROCESS TIME:											8	11.4%	8	11.4%	
GETTING TOOLS & RETURN															
LOOKING FOR MATERIAL		1				1	1				3				
POWER OUTAGE															
WAIT FOR MACHINE															
EQUIPMENT BREAKDOWN															
[illegible]	1				11		1	1			5				

WORK ORDER # 251-022 (525) | ESTIMATED HRS. 60 | CHARGED HRS. | SCHED. STD. HRS. 12

IPE ETAIL # 52)	MAT'L	SIZE	TIME SHEET DATA SAWING	BENCH TIME	DELAYS	BENDING	INSPECT	SPECIAL WORK	TOTAL	MOST DATA MECH	BEND	LEVEL (C 2)	WORK MEAS. DATA W/AVOID. DELAY	NON-PROCESS	TOTAL	SCHED. STD.	
EB	STL	4	[redacted]	1.25					4.25	0.98					0.25	1.23	
EC			0.25	0.50	1.50				2.25	0.98					0.25	1.23	
ED			0.75	1.00					1.75	1.30					0.34	1.64	
EE		2½	[redacted]	1.25	1.75	0.75	0.75	1.00	7.25	1.30	0.32	1.62			0.42	2.04	
EF		3	[redacted]	1.50					3.50	1.30					0.34	1.64	
EG			0.50	0.75					1.25	0.98					0.25	1.23	
EH			[redacted]	0.75					2.25	0.98					0.25	1.23	
EJ			[redacted]	0.50	1.00	0.75			3.25	0.98					0.25	1.23	
N			4.00	0.75	3.00	4.00	0.75	1.25	13.75								
									39.25	8.80	0.32	9.12			2.37	11.49	